old gulf salt was deposited in large amounts, and forms to-day an important addition to the mineral wealth of the state. No salt is now found close to the gypsum, and if it did exist it has been removed by solution. The irregular upper surface of the gypsum shows that there has been solution in some places where large quantities of gypsum rock have been carried away.

The swamp deposits of earthy gypsum have probably been formed by deposits from springs, aided by wash from the hillsides, and they are recent in age.

The southern gypsum was deposited in a shallow gulf cut off not far from the close of the Permian time. As in the northern gulf, a salt deposit occurs to the southwest in the salt-plains district; but no trace is found near the gypsum.

THE STUDY OF NATURAL PALIMPSESTS.

By G. P. Grimsley, Topeka, Kan. Read (by title) before the Academy January 2, 1897.

Paleontology has revealed a long life-history from Cambrian time to the present, and has vainly attempted to read the obscure pages of earlier history of Archæan time. Baffled at every turn, the search was abandoned; but a new science has boldly entered the field, and the mysterious pages furnish a history for the petrographer, which in interest rivals that of the paleontologist.

This record is not written in fossil letters, but in mineral characters, which so long have been meaningless geoglyphics. In making the so-called prehistoric record, nature has been economical in materials and in space. She has erased some portions of the ancient record with the cleansing force of fire, rewriting on the same tablets of stone the records of new conditions.

The discovery that many of the records of ancient historical time were written on erased parchments of an earlier day, and that a careful investigation would reveal many of the first records, was a historical triumph. The students of ancient languages have enriched the world by their painstaking search through old literary palimpsests. In the past decade the students of nature have discovered the existence of *natural palimpsests*, and they are now endeavoring to read the imperfectly erased records of the past, and thus add new chapters to the history of the earth. To the process of erasure and rewriting these investigators have given the name *metamorphism;* and the natural palimpsests are called *metamorphic rocks.*

The studies of biologists have shown that throughout organic nature there is a most delicate adjustment to environment. The researches of petrographers have shown that in the inorganic world minerals are so delicately adjusted to surrounding conditions that changes in the latter are recorded by variations in the minerals. The recognition of this fact in recent years is the foundation of the new knowledge concerning the Archæan period.

According to the Wernerian theory of the last century, crystalline rocks were deposited as chemical precipitates from a primeval heated ocean before life existed. They were produced at their origin as they exist to-day. Near the close of the century, Hutton found granite dikes penetrating other rocks, thus proving an igneous origin. He then advanced farther and formed the interminable cycle, stating that rocks were decomposed by atmospheric action, the detritus accumulated at the bottom of the sea, where under the pressure and heat it was rendered crystalline, and later elevated to pass through the same series of changes without trace of beginning or prospect of end. The theory of the transformation of rocks under heat and pressure originated at this time in this rudimentary form in Scotland. Bone and Necker, nearly a quarter of a century later, transported the theory from this Plutonic region to Europe, where it reached greater development. The Alpine region, on account of the great forces at work and the gradations in effects, from the simple to the complex, soon became a classic region for the study of rock alterations. In 1826 Beaumont recognized that in this region the phenomena were not confined to the oldest rocks. He observed that Jurassic fossil sediments had been changed to crystalline rocks. The old Alps now became the new Alps, and the interest in the region was greatly increased.

In the process of adjustment of the minerals or rocks to changes in their environment, new elements are often added and old ones removed. If the changes take place at the surface of the earth, under ordinary atmospheric or aqueous influences, they are included under the term *weathering*, and the result is usually disintegration. True metamorphism is connected with igneous and dynamic agencies; and while the word was first introduced by Lyell, in 1832, it was not clearly defined until 1846, when Durocher described metamorphism as the sum total of all modifications in texture or structure to which rocks in nature are subjected. Daubrée limited the definition to those modifications whose causes were fire and water, and Beaumont added the agency of mineralizers. The word *metamorphism* is now cosmopolitan, though given different limitations by different authorities.

American geologists from an early day have been prominent in this field of study. The pioneers composing the American metamorphic school — Hitchcock, Mather, Dana, Logan, Rogers brothers — were active students of those altered records, and they made many valuable observations. They all regarded the process of metamorphism as confined to the sedimentary rocks, a view which long retarded progress in the work. When foliated or parallel structures were observed in metamorphic rocks, they were regarded as the old sedimentary lines which survived the alteration. A voluminous literature descriptive of this limited field of altered sediments soon filled the shelves of science.

Down to the year 1875 the province of metamorphic action was thus confined to the sedimentary rocks. About this time appeared the epoch-making works of Heim, in the Alps, and of Lossen, in the Hartz, whereby it was shown that igneous rocks could be changed by metamorphic action.

On account of the interesting and inviting problems connected with this study, it has attracted the attention of many of the younger workers; and the result has been a very great advance in our knowledge of these broken and crumpled rocks, though the vast field yet remains practically unexplored.

Metamorphism may refer to any changes in rocks, but it is restricted now to include the changes whose conditions lie intermediate between fusion and ordinary atmospheric action. The limits are not sharply defined, so metamorphism grades below into igneous action, and above into atmospheric action or weathering. Metamorphic rocks may be further metamorphosed, so that all rocks, sedimentary, igneous, and metamorphic, are subject to metamorphism. The agencies at work in this great process are both physical and chemical; and they are classified according to the preponderating influence. If the temperature and pressure are low the action is due mainly to water, producing *hydro-metamorphism*, resembling very closely weathering. If temperature is high and pressure is low, and mineralizers — gases whose presence facilitates fusibility — are present, the action is described as *sublimation metamorphism;* or, if water alone be present, the action is described as *thermo-metamorphism*. Static metamorphism includes those changes where pressure is mainly active and where motion is absent. If motion is present, the changes come under the division of dynamic metamorphism. All of these alterations take place without any material change in the bulk composition. Static metamorphism, though not accepted by many geologists, has able defenders in such men as Hall, Judd, and Spring. Dynamic metamorphism has been firmly established by the classic works of Heim, Lehman, and Balzer.

Metamorphism may be produced by the presence of some metamorphosing agent, and it is then termed *contact metamorphism.* The alteration in surrounding rocks may extend over a distance from a small fraction of an inch up to 4,000 feet, as seen in the Pyrenees. The nature of the contact metamorphism depends on the duration of the action, the depth at which the alteration takes place, whether deep enough to prevent the escape of vapors and moisture, or not; and on the nature of the metamorphosing agent, whether it is a granite, diabase, or other rock; and also on the nature of the rock altered, whether crystalline schists, carbonaceous rocks, sandstones, or igneous rocks. The nature further depends on the structure of the rocks, whether foliated or not, as demonstrated in Brittany by Barrois.

Rosenbusch, after careful examination of analyses, concludes that there is no change in the bulk composition of the altered rocks, though Michel Levy insists that there is always a very considerable addition of substance.

The effect of contact metamorphism on crystalline schists is less intense than on most of the rock types. The effects, consisting mainly of the formation of new minerals, as andalusite, sillimanite, and garnets, have been described in the Cortlandt rocks by the late Dr. G. H. Williams. The effect of this form of metamorphism on carbonaceous shales is to form a graphite, or the diamond, as in the South African region. The effects of contact action on clay slates have been described at a number of regions which serve as types: at Barr Andlau, in Germany, by Rosenbusch, by Lossen in the Hartz, by Allport and Phillips in England, by Barrois in Brittany, by Brögger in Norway. In these various regions it has been noted that the intensity of metamorphism at any given point is proportional to the nearness of the intruding rock.

In limestone contacts the conditions are very favorable for the tracing of the beginning and development of the metamorphism. The limestone is observed to become more and more crystalline as the intrusive rock is approached and the carbonates change to silicates. These changes are observed in the well-known limestone contact region near Christiania, Norway, and the famous mineral locality of the Fassathal, in the Tyrol. Contact action on igneous rocks has been observed at but few places. It has been described by Lossen in the Hartz mountains.

The pioneer in the study of dynamic metamorphism was Lossen in 1867. In 1878 Heim published his great work, the result of a long field-study of the Alpine rocks, in which he developed the theory that even the most brittle rocks under pressure acted as viscous bodies, and were deformed without rupture. Spring and Guembel endeavored to prove this theory by actual experiment, but the rocks were crushed to a fine powder.

In 1884 Lehman, as a result of microscopical study of the crystalline schists of the Alps, concluded that the rocks were crushed and recemented under great pressure, thus producing an effect similar to viscous bodies, a process which might be described as rock regelation. These two works marks a new phase in the study of metamorphism the world over, through the recognition of the fact that *foliation* in rocks is wholly independent of original structure. Parallel arrangement in rocks is not proof of sedimentation, a view which before this time was not recognized.

Heat, water, and pressure are great agents of metamorphism, and they produce three kinds of alterations in rocks — mineral, microstructural, and macrostructural changes. Under mineral changes, we have among the alkaline silicates the alteration termed *sericitization*, forming an intercalating network of hydromicas. Also *saussuritization*, embracing the changes whereby plagioclase feldspar is converted into alkaline earth silicates. In *albitization* the feldspar is changed into an interlocking albite mosaic. Among the iron-magnesian silicates occurs: *uralitization*, where pyroxene is changed into fibrous hornblende; *viridization*, or formation of green epidote chlorite mass, analogous to saussuritization; *chloritization*, and *epidotization*, analogous to albitization.

Under microstructural changes are observed the strain phenomena in crystals, recognized by polarized light in a wavy extinction of light as the section is rotated. If the strain has been carried farther, gliding or twin lamellæ may be observed, as in the metamorphic marbles. Progressing to greater extent, the minerals are bent, twisted, and finally broken into an irregular mosaic, composed of interlocking mineral grains. Sometimes there is a stretching of the rock along certain lines, pulling the grains apart.

Under macrostructural changes, the most prominent is the formation of secondary foliation, or an arrangement of the minerals along parallel lines, which were so long taken as evidence of stratification. Though this distinction between foliation and sedimentary lines was noted early in the century by Voigt, Mohs, and Schmidt, it attracted little attention. Later it was observed that the lines were parallel over extensive tracts, even when the rocks were crumpled. This was explained as the result of crystalline force or the result of electric currents passing around the earth. In 1846 it was shown to be due to pressure normal to that which developed the foldings.

Such rocks, which possess this secondary foliation, are called *crystalline schists*. This is purely a structural term and has no connection with age. While most of these rocks are pre-Cambrian, there are numerous exceptions. The schists are divided into two main groups, those with feldspar and those without this mineral; and the former are called *gneisses*. This usage makes gneiss a mineralogical and structural term; mineralogical in that it contains feldspar, structural in that it is foliated. If the origin of the gneiss is determinable it has the original rock name added as a prefix. Thus, a secondary foliated conglomerate is called a conglomerate gneiss. A foliated granite is a granite gneiss. When the word *gneiss* is used alone it represents a foliated feldspathic schist of unknown origin.

Down to the end of the last century geology was a collection of hypotheses and sacred theories of the earth. Its students then began to observe and record facts, and later to form theories based on such observed facts. The study of the igneous rocks passed through a similar course of development. The study of the metamorphic rocks is now passing through such a course and it has entered the descriptive stage. It is now at the point reached by general geology in the time of Lyell, and reached by the study of the igneous rocks in the year 1870.

The study of the crystalline schists, both of Archæan and post-Archæan time, now becomes the great field for work, and all over the world students are trying to trace their origin and formation.